ADVANCED SENSORS, TELECOMMUNICATIONS AND
DATA PROCESSING: TECHNOLOGICAL SPIN-OFFS
FROM THE STRATEGIC DEFENSE INITIATIVE

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ADVANCED SENSORS, TELECOMMUNICATIONS AND DATA PROCESSING: TECHNOLOGICAL SPIN-OFFS FROM THE STRATEGIC DEFENSE INITIATIVE*

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ABSTRACT

While the details of Nitze Criteria-satisfying architectures for defense against strategic attack with ballistic missiles are still being worked out, it is already clear that quite advanced sensors, telecommunications and data processing technologies will be features of all of them. It is concluded that the SDI, due to its institutional youthfulness, its charter for large-scale research and its self-evident need for such technologies, is likely to dominate many aspects of these technology development areas during the next two decades, especially if it continues more-or-less as the current American Administration contemplates. Both the technical and the economic aspects of data-gathering and manipulation seem likely to be substantially enhanced, due to the existence of the SDI.

Background

The Strategic Defense Initiative was called into existence on March 23, 1983 by Ronald Reagan, President of the United States, to determine in a multi-year research program whether defense against attack by strategic, nuclear explosive-tipped missiles was feasible. Subsequent declarations and directives from senior officials of the American Administration have specified the criteria by which feasibility should be assessed, the all-inclusive nature of the defense which is of interest, the necessity for defense against all other modalities of strategic attack, and the international framework within which the questions of feasibility would be investigated. Several of the major member nations of the Western Alliance have joined the American-led research effort through the present time, and the eventual participation of others is expected.

It is notable that few serious Western observers have faulted

● the Nitze Criteria for assessing the feasibility of strategic defense;

● the long-term focus of the program on general defense of populations to the point that nuclear-armed missiles become "impotent and obsolete;"

● the consistency of the declared program against all types of strategic nuclear attack and the emphasis on non-nuclear means of strategic defense;

● the participation of the Allies in all aspects of the strategic defense research program and the negotiated sharing of the benefits of strategic defense technology with the governments of all nations.

Having agreed—if only tacitly—on essentially all of these fundamentals, most of the serious participants in the ongoing debate regarding strategic defense have focussed, perforce, on guessing what answers regarding feasibility will be provided by the research program, when it culminates in the early 1990s; only a handful persist in questioning the honesty or the sanity of American President and of the senior members of his Government in their pursuit of strategic defense along these lines. These guessed-at answers are then often employed in attempts to influence present policy decisions regarding national and international security.

The essential foolishness of this activity has been quite effectively obscured by the extensive participation in it on the part of the Soviet Union. The U.S.S.R., which has made a very large investment in strategic nuclear offensive capital plant whose geopolitical benefits it has only recently commenced to enjoy, is understandably reluctant to even consider its liquidation as a consequence of a Western technology initiative. Insistence by Soviet spokesmen of all stripes, both in the East and in the West, that the Strategic Defense Initiative is somehow both futile and dangerous has lent an air of seriousness to the SDI debate in the West, notwithstanding the manifest disingenuousness of the Soviet stance vis-a-vis its own very large efforts in this area. This seriousness is largely due to the unprecedentedly strident manner in which the Soviet Government has addressed itself to this issue in Western forums.

Just because of this striking Soviet activity and its possible effect in impeding the SDI, it is worth noting that it is not necessary for the Strategic Defense Initiative to succeed, in the ultimate sense in which President Reagan spoke on March 23, 1983, or even for it to be seen by some future President and future Congress to satisfy the Nitze Criteria for judging the effectiveness of defenses, in order for it to have profound implications for information science and technology. In particular, the technical and economic consequences—the technological

spin-offs—of the SDI may come into existence almost independently of the perceived success or failure of the SDI to profoundly alter how superpowers conduct their geopolitical business. Thus, it may be sufficient simply for the SDI effort to be made, in order for the digital data-sensing, -transmission and -processing technologies to be strongly affected.

Pertinent Aspects of the Strategic Defense Initiative

It is appropriate at this point to note explicitly those aspects of the Strategic Defense Initiative which are possibly pertinent to information science and technology.

As noted above, the basic goal of the Strategic Defense Initiative is to establish the feasibility, according to established criteria, of defeating a massive strategic attack with nuclear-tipped ballistic missiles so definitively that such an attack becomes such an unattractive option under whatever circumstances are most favorable to it that it would never be launched, and so that such means of attack therefore become "impotent and obsolete." Feasibility in this context thus implies not just the ability to largely obviate the means by which such an attack would be conducted, so that an attack against a superpower's military plant would necessarily fail to destroy it; strictly construed, it implies an ability to so completely obviate the attack that damage to the most sensitive portions of a nation—e.g., cities—would be sufficiently small under the worst of circumstances—e.g., a pure countervalue attack—that it would be "acceptable" by the nation so attacked. Indeed, it is around this issue of "strict feasibility" that the most discussion and controversy has swirled; it has quantitative, though probably not qualitative, implications for the question of the SDI's impact on information science and technology.

A nuclear ballistic missile attack must pass through several successive phases from its commencement to its culmination in a set of explosions on the territory of the nation being attacked. In principle, the attack may be frustrated by thoroughly disrupting it in any of these phases—boost phase, post-boost phase, mid-course phase, high terminal phase, low terminal phase. In practice, it is prudent to plan to *totally* disrupt it in each one of these phases by independent, non-cooperating means, i.e., to completely win the defensive battle not just once but many times over. *I expect all of the really serious competing architectures for a strategic defense system to share this characteristic of fully redundant, total victories in each and every phase of the strategic defense battle.* Such a basic feature again has quantitative, and perhaps even qualitative, implications for information science and technology, as system architectures possessing this feature must have much more capable technical aspects than ones which do not.

The ability of a strategic defense system to survive and function adequately both in nominal peacetime and during all-out strategic war (as well as in the many stages in between) is basically what the Nitze Criterion of "robustness" requires. Survivability and adequate retention of functionality in the face of what is called "a fully responsive offensive threat by a capable and determined adversary" places stringent requirements on a strategic defensive system, so much so that the technological alternatives which the SDI is exploring will necessarily be assembled into candidate system architectures which will be quite different from those which have been publicly discussed through the present time. The nature of the actual strategic defense systems which may be called into existence by some future American government will impact the prospects for international cooperation in space rather differently than

those most discussed publicly through the present time.

Similarly, the Nitze Criterion of "cost-efficiency at the margin" imposes an economic constraint which must be met by serious candidate technologies and the system architectures constituted of them; some fraction of the most publicly discussed options may not satisfy this constraint, and the impact of the surviving technologies and the associated systems on the development of information science and technology will shift correspondingly.

In order to perform its mission, a strategic defense system must detect an attack, locate the physical elements comprising it, determine which of these elements constitute real (vs. illusory) threats, determine how to most effectively neutralize these elements, attempt their neutralization, assess the success of the neutralization attempt, and iterate until neutralization is complete. In the process of doing so, it will itself undergo neutralization attempts by the attacker, and must both capably resist these attempts and continually re-constitute itself against the damage which it nonetheless sustains.

The elements of such a strategic defense system may be grouped by functional category into three basic groups: sensors, data processors and telecommunicators, and effectors. The sensors are the eyes-and-ears of the system, while the data processors and telecommunicators are its central nervous system, and the effectors are the hands and arms. Each of these three groups currently seem likely to require capabilities well advanced compared to the current state-of-the-art, and constitute a major part of the enhanced technical substrate for international cooperation in space being created by the SDI, as will be noted subsequently.

Where these elements are located spatially and how and when they get to such locations in order to perform their functions are also significant. While *some strategic defense systems meeting the Nitze Criteria may be completely ground-based* and may insert components into space only in time of war, many to which great current interest attaches are based at least in part in space. Space differs from the normal domain of human activity mainly in being nearby but nonetheless very difficult to get to. The cleverness of information technologists in realizing sensors, telecommunications and data processing systems adequate for the strategic defense job will set the lower bounds on how extensive must be the advances in space transportation necessary to implement robust strategic defenses; the greater the cleverness, the less demanding will be the development of the supporting space transportation system.

Before leaving the discussion of the general features of the SDI, it is appropriate to caution once more that public discussion of details of the SDI is based almost completely upon the fantasies of media people with minimal technical backgrounds or upon the "straw men" erected for ease of demolition by SDI critics. An outstanding, but by no means exclusive example of this free-floatingness of the *publicly discussed* SDI is the universal media characterization of the deployed form of SDI as "space-based," though no responsible American Administration spokesman has ever given support to such a description. The official characterization of the possible deployed strategic defense systems arising out of the SDI has been essentially devoid of detail or specifics, consistent with the declared policy of the American Administration to not pre-judge the results of the SDI research program.

SDI Interaction With Information Science And Technology

It is now timely to consider particular aspects of the interaction of the Strategic Defense Initiative with the various areas of the information sciences and technologies, specifically in the areas already noted above as traditional functions of government. The examples given are intended to serve as daubs of color on an otherwise blank technological canvas, one whose area is to be covered mostly with items whose shapes will become clear only with the passage of time.

National Security. The principal threat to the perceived security of a nation is attack from abroad, whether of the classic over-the-border-with-armies variety or the neoclassic kind involving bombardment with nuclear-tipped long-range missiles. Much of the dread and considerable fractions of the effectiveness of such attacks depend on their hidden natures; all nations would surely be more secure and perhaps even less bellicose with respect to their neighbors if there were no such thing as a surprise attack of either the classic or the neoclassic kind.

The extremely high-speed location to exceedingly great precision of very many possibly threatening objects—ballistic missile boosters, MIRV buses, thermonuclear warheads—and their classification and analysis are obvious tasks which must be borne by the sensor and data-processing sub-systems of any capable strategic defense system. A far less demanding task to which these capabilities could be applied would be an internationally created and operated surveillance system which would monitor all territory of all nations for the unmistakable features of impending large-scale military operations of all kinds—and only for these features.

Such pattern-matched and threshold-filtered reconnaissance information, available in real-time to all nations, could serve to eliminate the possibility of surprise large-scale attack without infringing on any conceivably legitimate aspects of national sovereignity. Only a nation plotting armed aggression against another nation—a cardinal violation of international law—could object to operation of such a system. This is of course a limited—though still potentially highly valuable—implementation of President Dwight Eisenhower's "Open Skies" proposal, a proposal which I understand is still backed by the U.S. Government through the present time, and which I believe has substantial support in the Federal Republic at the present time.

One of the most obvious modalities by which large advances in information gathering, transport and processing may be stimulated as a result of the SDI is in the joint creation and operation of means for suppressing surprise attack of nation upon nation, not just by obviating the element of surprise but also by guiding the neutralization of the means of conducting all such attacks. The SDI, via exploitation of advanced information technology, thereby may make not just nuclear-tipped ballistic missiles but also much of the other machinery of large-scale armed conflict "impotent and obsolete." I will speak subsequently to some of the technical prospects in this area.

Information Transport and Processing. The Japanese Government, in its chartering of the well-known Fifth Generation Computer initiative, became the first major government to formally recognize what has become widely realized by now: the dominant cultures of even the early part of the 21st century will be those which have most successfully mastered the flow and processing of streams of information on scales which are enormous by present standards.

Creating the hardware substrate upon which information-intensive cultures can build the software and systems structures of the so-called "fifth generation" computing systems is the task of several national and trans-national projects already underway, of which the Japanese one was the first to be formally chartered. However, it is certainly far from clear at present what types of hardware, software and systems structures will be the most successful in each of the only poorly characterized areas of information processing which will be important even two decades hence.

It is substantially more clear what types of telecommunications and information processing structures will be required for the various leading candidate architectures for SDI purposes. Because at least some of these are likely to be realized for feasibility evaluation and validation purposes and because they seem likely to be far in advance of contemporary systems, they may well serve as the first really serious instantiations of the basic machinery of what the Japanese first called "the information society."

That major candidate architectures for SDI purposes will involve distributed information processing capability, rather than concentrated central processing, has become clear during the often-public technical debate during the past year or so on SDI computing system feasibility and reliability, during which the SDI computing system architects re-learned the lessons which military computing systems designers had mastered long before. While the processing nodes of such systems will have less computing power than was contemplated for the SDI central processing system, the aggregate computing power of the system will be far greater; cheap, reliable distributed hardware resources will be pervasively substituted for expensive and less reliable centralized software ones, and many computations will be performed redundantly.

Similarly, the information transporting capabilities will be netted in a highly redundant fashion, probably using the extensively investigated packet-switching network technology. Again, cheap hardware will be used redundantly in place of expensive software to provide very high system reliability in the face of widespread, unpredictable damage levels.

The processing capacities *at each node* in candidate SDI networks are likely to be rather staggering, simply because exceedingly high performance levels *can be realized inexpensively* and *may be useful operationally*. Highly concurrent information processing appears likely to be the order-of-the-day, and *nodal* computing structures containing tens of thousands of microprocessors, or millions of what might aptly be called "nanoprocessors," are being actively considered by computing systems designers working under SDI auspices.

The aggregate information processing capability of the most powerful of these poly-nodal systems will approach ten *trillion* elementary logical or arithmetic operations per second, many thousands of times greater than that of contemporary supercomputers. The ability of such structures to have their very high-speed components cooperate closely implies that they must also be quite compact; current designs are a small fraction of a cubic meter in volume. Such compactness is a necessity from other standpoints; one such processing structure may well be embedded in each SDI sensor or weapons platform, of which there may be thousands in some architectures, and in which both mass and volume may well be at a premium, e.g., in those platforms which must be launched rapidly into space from the ground in wartime. I will give examples of such features below.

To exchange information at appropriate rates between all such nodes—e.g., between the entire set of weapons and sensor platforms of a strategic defense system—will require data

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transport capabilities which are very great by most contemporary standards. The most modern telephonic networks send information digitally at rates of several hundreds of millions of bits per second on single fiber-optic lines, and laser-based military space data links of an order-of-magnitude greater capacity have been demonstrated in sub-scale. It presently appears likely that typical strategic defense system single data channels will have capacities of the order of ten billion bits per second—sufficient to transmit all of the precise locations and speeds of all of the several million "threat objects" in a mid-course battle in less than a tenth-second—and that as many as thousands of such channels will exist at any given time. Such enormous excess capacity of course permits exceedingly severe damage levels to be sustained without loss of critical system data transmission performance or connectivity; their optical laser implementation provides not only very high bandwidth but also robustness in the severely disturbed transmission and reception environments which might exist in a strategic defense battle. As in the case of data processing, the relatively very low cost of the pertinent hardware will be used to minimize expenditures in system design and implementation, including software generation and qualification.

Weather-Coping. Human activities directed toward coping with the weather greatly predate the advent of governments, which thus far have served mainly to lightly organize many such activities. The preeminent example of such organization is the generation and distribution of predictions of weather for the coming few days; most such predictions are slightly more reliable—and thus more useful—than those provided by tribal shamans in times long past. Governments still mostly talk about the weather; few do much that anyone seriously believes will improve or even change the weather. The weather, however, impacts the human condition more pervasively than does just about any other aspect of our physical existence.

It seems likely that both of these present governmental relationships with the weather—poor ability to predict it and negligible capacity to improve it—will change substantially in the next quarter-century. Indeed, it appears that some aspects of weather-prediction ability may be significantly impacted—mostly, accelerated—by SDI research activities.

The most obvious and least controversial fashion in which this will happen is in the area of greatly improved weather predictions. As already noted, all passive sensing abilities in the human "technological bag" are likely to be greatly enhanced by the SDI technology thrust in passive sensors, which is seen as crucial to the ability to locate and to classify threatening objects in space. Such sensors will have spatial, spectral and temporal resolutions very far in advance of the best present ones; they will be compatible with operation in space, and they will be created in quantity. As a result, the human ability to sense in exquisite detail the physical features of the biosphere—e.g., the ground and air temperatures, the wind speed and direction, the humidity—all over the planet will be enormously enhanced; the ability to process, condense and transmit such information will gain similarly, for similar reasons. Everything else being equal, human weather prediction capability will advance substantially as a result of SDI research, just because the data streams inputted to the prediction process will be of much higher quantity and quality.

However, everything else will not be equal. Modern weather prediction capability is rational; it is based on inputting current atmospheric conditions into computer-based models, which express the laws of nature which apply to weather systems, and then asking these mod-

els what the consequences of these particular current conditions will be one, two and perhaps even five to ten days hence. Now, the feasibility-in-principle of computing predictions of the weather is presently a hotly debated topic in the pertinent portion of the scientific community. It is not at all clear that it is possible to accurately predict, for example, what the amount of snowfall will be here during the first ten days of next January, no matter how powerful the computers or how accurate the measurements of present conditions one may have. The weather may simply not be amenable *in principle* to accurate prediction beyond a certain distance—perhaps somewhere around two weeks—into the future.

Most people, however, would be satisfied to know what type of weather they will be experiencing in the next few days; next month's weather is generally of interest only when it approaches much more closely in time. To this very large majority of the human race, computer-based weather prediction has a very great deal to offer. The feasibility of accurately predicting weather all over the American continent several days into the future, using very powerful computers which start with complete, timely satellite-observed conditions, has been demonstrated on a research scale in the past few years. Making such predictions routinely available to everyone is estimated to have favorable economic consequences of a few dozen billions of dollars each year to the U.S. agricultural community alone, with a total annual benefit to the American economy approaching 100 billion dollars. The corresponding benefits to Europe might be expected to be comparable.

Now, the laws of nature which must be evaluated in detail via computers to perform rational weather prediction are similar in their basic mathematical form to the natural laws which govern much of the strategic defense battle. Thus, the computing engines of prodigal capacity which are being created to solve the computational portion of the strategic defense problem—engines which perform a very large number of similar calculations concurrently—are likely to be remarkably well-suited to performing the work of weather-prediction, among many other things. Thus, it is an eminently reasonable expectation that relatively long-duration weather-prediction with high geographic resolution and strikingly high reliability—at least by current standards—will be commonplace a decade hence.

This expectation, as it spreads, may in turn induce a great deal more international cooperation in creating the means of gathering meteorological data with satellites bearing SDI-derived sensors and in getting these data streams flowing routinely into regional weather-forecasting centers equipped by SDI computing technology. SDI-derived information transport technologies will doubtless be crucial in these operations.

A Sampling Of SDI Information Technology Efforts

It seems appropriate before concluding to sketch a few examples of advanced information technology which is emerging under the auspices of the SDI research program.

Figure 1 illustrates a new type of optical system whose use will permit the creation of very wide field-of-view cameras with angular resolutions two orders-of-magnitude better than existing wide-angle photogrammatic mapping cameras. Such cameras offer the prospect of achromatically generating images with 10^4 times as many resolvable spots—potentially, 10^4 times as much image information—as can the best existing ones of their kind.

The best commercially available wide-field mapping cameras suffer from abberations which

permit them to resolve details in an image only a few times better than can the average human eye, working in the center of the human visual field, where the eye's resolution is best. This new type of camera can resolve more than a hundred times more finely than can the eye at its best in both the horizontal and vertical dimensions, and can do this all over its field-of-view, with a field-of-view comparably wide to that of the eye. (The eye, in contrast, has good resolution over less than one percent of its nominal visual field, and very poor resolution over the other 99+%.)

I find it remarkable that such large gains in camera performance remained to be made, more than four-fifths of the way through the twentieth century, and nearly two decades after computers began to be used in advanced optical system design. This is an outstanding example of how the need for greatly improved technical performance, laid before really capable and determined people, can often evoke striking advances.

At least as impressive with respect to technical advance is the digital solid state photodetection and image-processing system being developed for integration with prototypes of this new camera technology. A cut-away view of a second-generation system of this type, currently under development, is shown in Figure 2. This system actually mimics many of the basic functions of the mammalian eye and the visual cortex of the mammalian brain. It receives light projected onto its billions of photodetector elements by an advanced camera positioned in front of it, converts the light to electrical charge and currents represented in digital form, and then stores and processes this digital information in any of a very wide variety of ways, under software control.

A typical instantiation of this system will include about ten thousand each of advanced versions of the solid-state imaging elements used in portable video cameras and of advanced microprocessor chips, closely interfaced in pairs. Each microprocessor will have several very dense memory chips associated with it, to serve as storage areas for the data streams—really, raging rivers of data—coming from the photodetector imaging elements. The total number of transistors in the microprocessors of one of these systems will be in excess of ten billion, and the total number of bits of memory will be not a great deal less than a trillion; these compare with perhaps a million transistors and something of the order of a hundred million bits of memory in today's supercomputers.

Since these populations of data processing and memory elements are within striking distance of those in the human brain—though the electronic ones operate millions of times faster—it isn't surprising that they can perform comparably as impressive functions as the human visual system, albeit many thousands of times faster. For example, it is expected that a single such system will be able to image precisely every single one of perhaps a million "threat objects" present in the entire battle-space of the mid-course phase of a strategic defense battle, to track the positions of all such objects to part-per-million accuracy, and to continuously predict where all such objects will be at specified future times, also to such accuracies.

Employed as the "front-end" of a fire-control system, such an information system will confer very formidable capabilities on the defense. Differently programmed, such a system can serve as an exceedingly powerful reconnaissance machine—or as an Earth resource-surveying vehicle with really extraordinary capacities. It would differ from present-day systems of these types not only by its far greater resolution but also by its vastly greater field-of-view and its ability to not only store but process—and process in most sophisticated fashions—the image

information inputted to it. In addition to revolutionizing much of astronomy, such systems may also bring drastic changes to civilian surveillance and security problems, so much so that the streets of inner cities all over the world may become safe to walk at night once again.

One of the key technologies underlying systems of this type is is referred to as wafer-scale integration, or WSI. Indicated on Figure 3 is the impact that the introduction of this technology is having on the performance of the most powerful digital computer systems, the so-called supercomputers. Hybrid wafer-scale integration is the type being used to create the very advanced image-detection and -processing systems just sketched; it uses very high precision mechanical positioning systems and lasers, both computer-controlled, to interface large numbers of integrated circuits together every bit as closely as the highest technology will support. Monolithic wafer-scale integration, in contrast, actually laser-writes and -interconnects all semiconductor devices together on a single crystalline wafer of silicon, resulting in a manifestly monolithic integrated structure of mammoth proportions. It represents a major technological plateau for digital computing systems, one beyond which it is currently difficult to see.

Figure 4 indicates the basic features of the type of hybrid wafer-scale integrated circuits currently being prototyped for defense purposes. These circuits, which are created on a single silicon wafer perhaps a dozen centimeters across, have the capability of a contemporary supercomputer, but are, of course, far smaller and less massive. These systems feature what might aptly be called two-and-a-half-dimensional circuit integration; the active elements are draped and interconnected over highly folded surfaces, much like the architecture of the human cerebral cortex, and for similar reasons. As just noted, computer-controlled manufacturing equipment of a quite advanced nature is essential for rapid, economical creation of such systems; such systems have been developed specifically for these purposes.

These hybrid WSI systems provide examples of what I referred to above as the cleverness of information technologists strongly leveraging the space transportation issue in strategic defense. If information processing is done sufficiently well, the defense effector systems which are thereby controlled may have more modest capability and yet still perform their tasks sufficiently well; they may therefore be of much smaller mass and volume, and thus be more readily transported into space. The compactness and low weight—and, by implication, low power demands and modest cooling requirements—of these very powerful environment sensing/control information systems being prototyped for possible strategic defense applications are, of course, features which are highly valuable in many possible civilian applications for "smart" control systems.

Figure 5 illustrates a particular advanced packaging technology which is being prototyped for strategic defense information systems. Modern data sensory, communications and processing systems tend, by their advanced, exceedingly miniaturized natures, to be very delicate, while modern strategic nuclear war tends, by its very nature, to be very violent. Making such information systems function reliably in such harsh environments is clearly essential to the overall functionality of strategic defense systems, which in turn is crucial to ensuring that such systems never need to operate in wartime: only if their functionality is undoubted can it be assured that their functioning will never be required. Packaging of advanced information technologies which is demonstrably more robust—in every sense—than the defensive systems in which such packages are embedded is a key aspect of such assured functionality. Civilian life also offers a broad spectrum of quite harsh environments in which such durably packaged information systems may be highly useful, ranging from accident-immune automobiles

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to fire-fighting and -rescue robots.

These are a very small sampling of the many advanced information technologies being actively researched under SDI auspices, technologies whose civilian applications appear likely to drastically alter how information is sensed, transmitted and processed for peaceful purposes.

Conclusions

In the preceding, I have sketched a number of technology development and applications areas in which the Strategic Defense Initiative may make advances which will significantly impact the prospects for development of information science and technology during the next quarter-century.

Why it is reasonable to expect all of these to happen, relative to the far more modest accomplishments projected to be realized from the expenditure of the significantly larger sums which, e.g., DARPA and NASA, will make over the next half-dozen years is straightforward: the SDI is a relatively new effort, and is spending a relatively rapidly increasing amount of "new" money. The other Government agencies which have traditionally supported work in these areas, in contrast, are much more venerable organizations, staffed with far more senior technical and managerial personnel, provided with an almost constantly declining real budgets, and have institutional time-scales which presently extend for decades into the future. The SDI budget does not *yet* go in major part to the maintenance of the large "standing armies" of civil servants which populate technology centers whose principal *raison d'etre* is the personal pride and the reelection hopes of the local members of Congress, as NASA's budget does, nor is it owned in major part by the research communities which it supports, as is DARPA's. The institutional senescence of DARPA and NASA—perhaps the American Government's major players in the information science and technology fields—isn't at all abnormal, nor is the institutional vigor of the SDI; both are simply consequences of the ages of the three agencies.

The undeniable fact of the matter is that the SDIO presently is comparably vigorous, daring and productive as were DARPA and NASA in the 1960s; comparably striking technological accomplishments can be expected of it. As a direct consequence, the SDI is becoming America's "chosen instrument" in large areas of technology, not by virtue of a larger budget or a more sweeping mandate—neither of which it has—but simply because its resources are more rapidly increasing, its management is more daring and purposeful, and it has yet to become the captive of a community of contractors or the host of an army of civil servants. While the SDI budget is increasing much more slowly than did the Apollo Project budget in the mid-1960s—which essentially doubled every year for a half-decade—the research nature of its mandate gives it substantially greater flexibility in pursuing late-arising but potentially high-payoff approaches; no President has committed it to doing anything comparable to landing a man on the Moon in six years. This freedom from day-to-day programmatic and operational requirements also distinguishes the SDI program from other large DoD high-technology efforts, such as those conducted by the Air Force.

However, the SDI works in a far more politicized environment than did NASA's Apollo Program, which found itself transfigured into a national monument to a martyred President in just the period of its greatest fiscal need. A somewhat less favorable milieu assures that SDI's research goals will be attained more slowly, less certainly and less completely than

originally planned, at least when compared against the Project Apollo record. Also, the increasing polarization of support and opposition to the SDI along partisan political axes is a serious challenge to the program's leadership. Finally, both friends and foes of the SDI, in America and abroad, realize that it will age during the next ten years into a much less efficient operation, and the ongoing debate over the pace of SDI research has this basic consideration very much in mind, if not on the tongue.
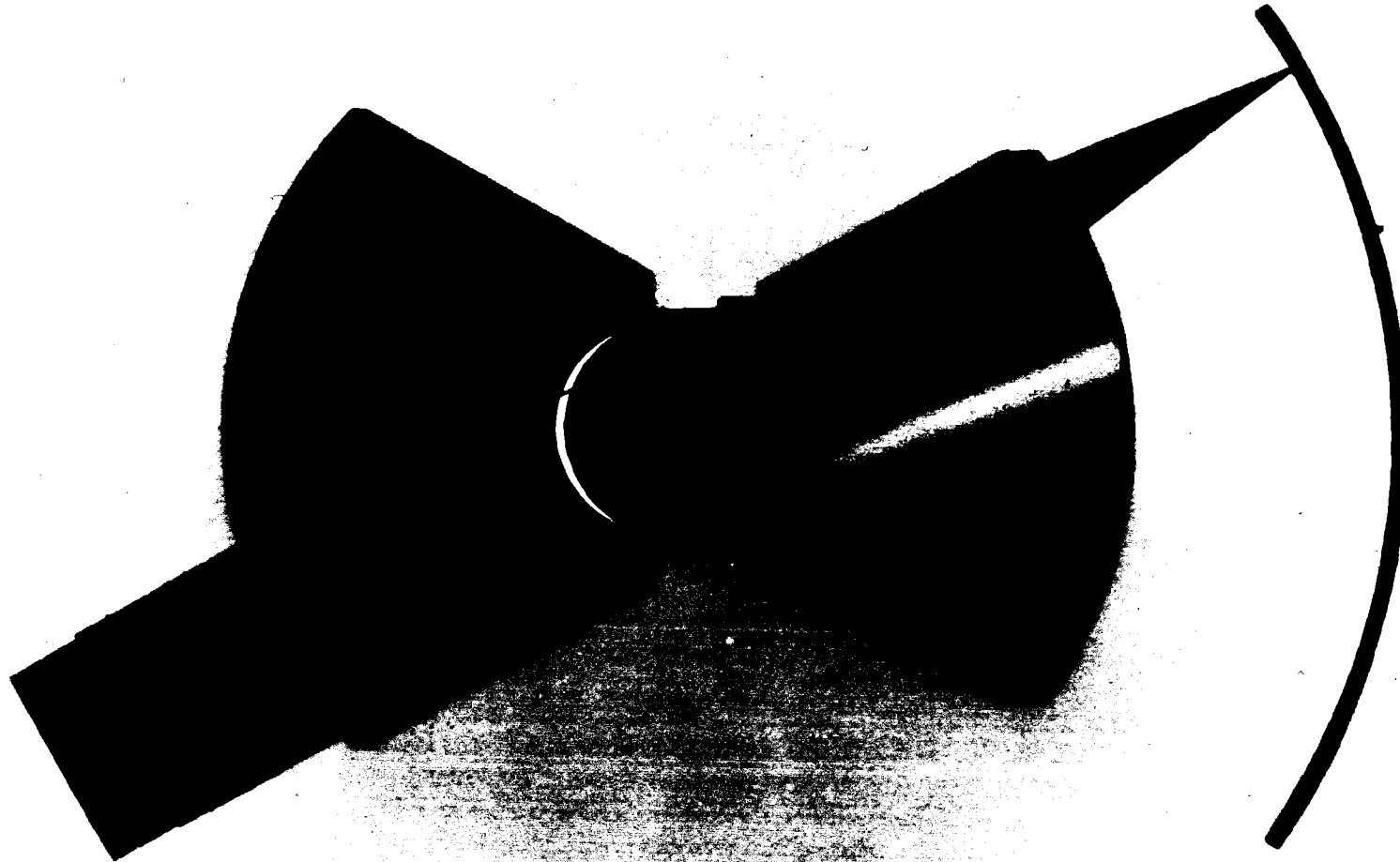
However, progress toward the basic technological goals of the SDI is presently being made at the brisk pace characteristic of the best sub-wartime American technical endeavors, e.g., that of the Apollo Project. Therefore, even if the program's budget continues to fail to grow at the full rate projected by the American Administration, many of the technologies sketched above are likely to be realized, albeit at later times. Only a near-term, complete-termination-with-prejudice of the SDI technology base efforts in, e.g., 1989, would suffice to abort most of these technology thrusts short of basic goal attainment. Most current predictions of the evolution of the American political scene indicate that this will not occur. It therefore seems likely that, whether or not some Congress and some President in the 1990s decide to select some candidate SDI architecture for deployment, the SDI technology base efforts will come to fruition, albeit somewhat behind the original schedule of the current American Administration.

Because these largely information-oriented technology base efforts are effectively the only broad-gauged, generic ones underway in the U.S. at the present time, because this situation seems unlikely to change in the foreseeable future, because the U.S. effort seems likely to dominate all others in the West into the indefinite future simply by virtue of differing prioritization of national choices by the leading Western states—with the notable exception of Japan—I suggest that SDI technology efforts will provide many of the building-blocks with which the advanced information technologies of the nations of the West will be constructed during the next quarter-century. Obviously, none of these reasons is compelling by itself; taken together, however, they define the maximum-likelihood projection of the development of the "information society" of the West.

The generally high-risk/high-payoff character of the SDI technology base programs and the declared policy of the SDI leadership to fund all promising approaches to SDI goals by continually shifting resources from relatively slowly developing options to the more successful ones essentially guarantees that the brightest prospects for technological advance in many aspects of information technology will be explored and developed. Such a program strategy inescapably develops many of the technologies which will be central to information gathering, transport and processing in the next two to three decades, and which therefore constitute the technical basis for the emerging "information society." The major scale of the SDI research program considered, both relatively and absolutely, it appears likely that this program will greatly enhance the technical basis for the "information society" for all of its participants.

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HIGH RESOLUTION CAMERA

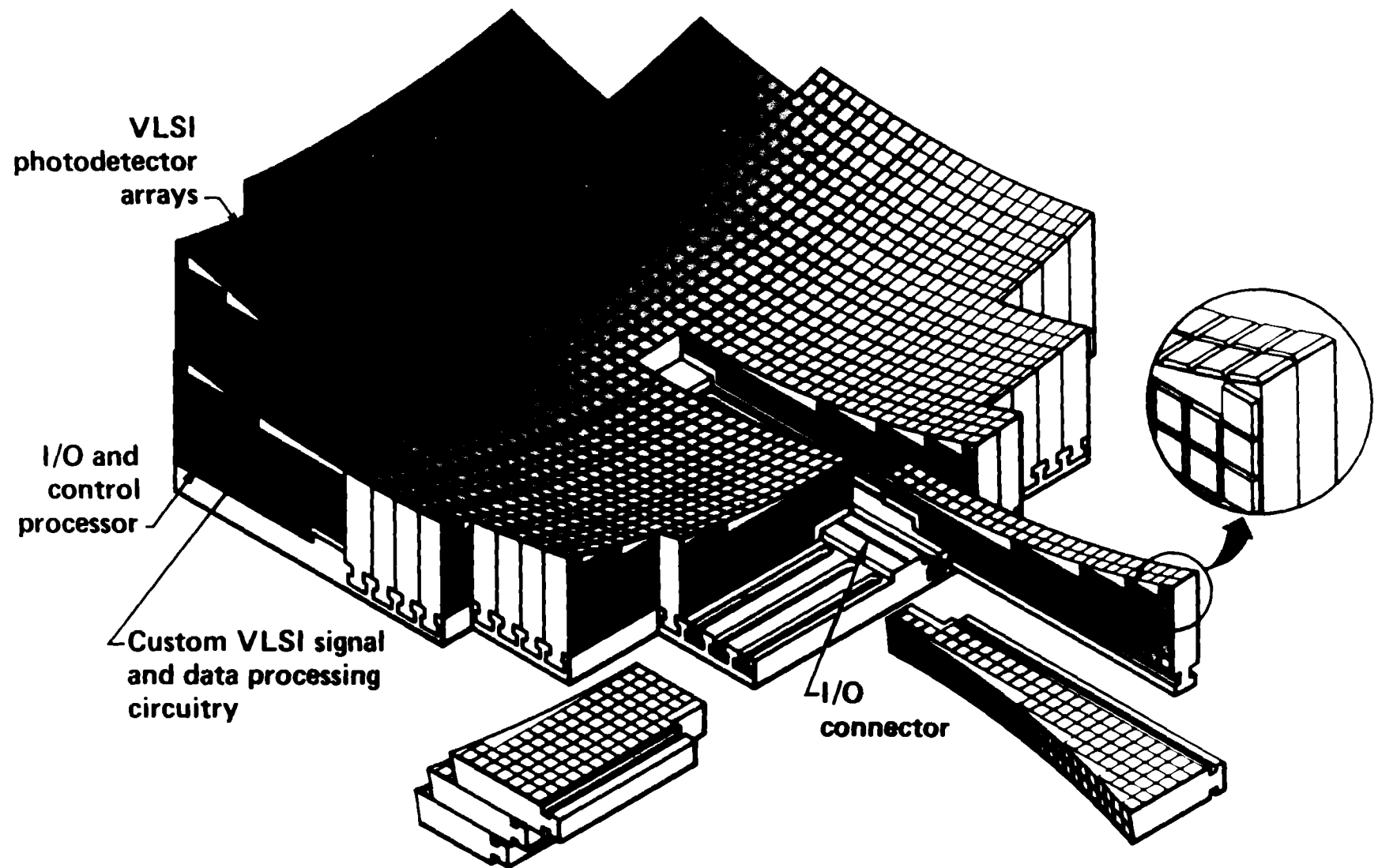# Second generation wide-field-of -view camera electronics

VLSI photodetector arrays

I/O and control processor

Custom VLSI signal and data processing circuitry

I/O connector

Figure 2

Impact of Technology Improvements
on Supercomputer Speeds
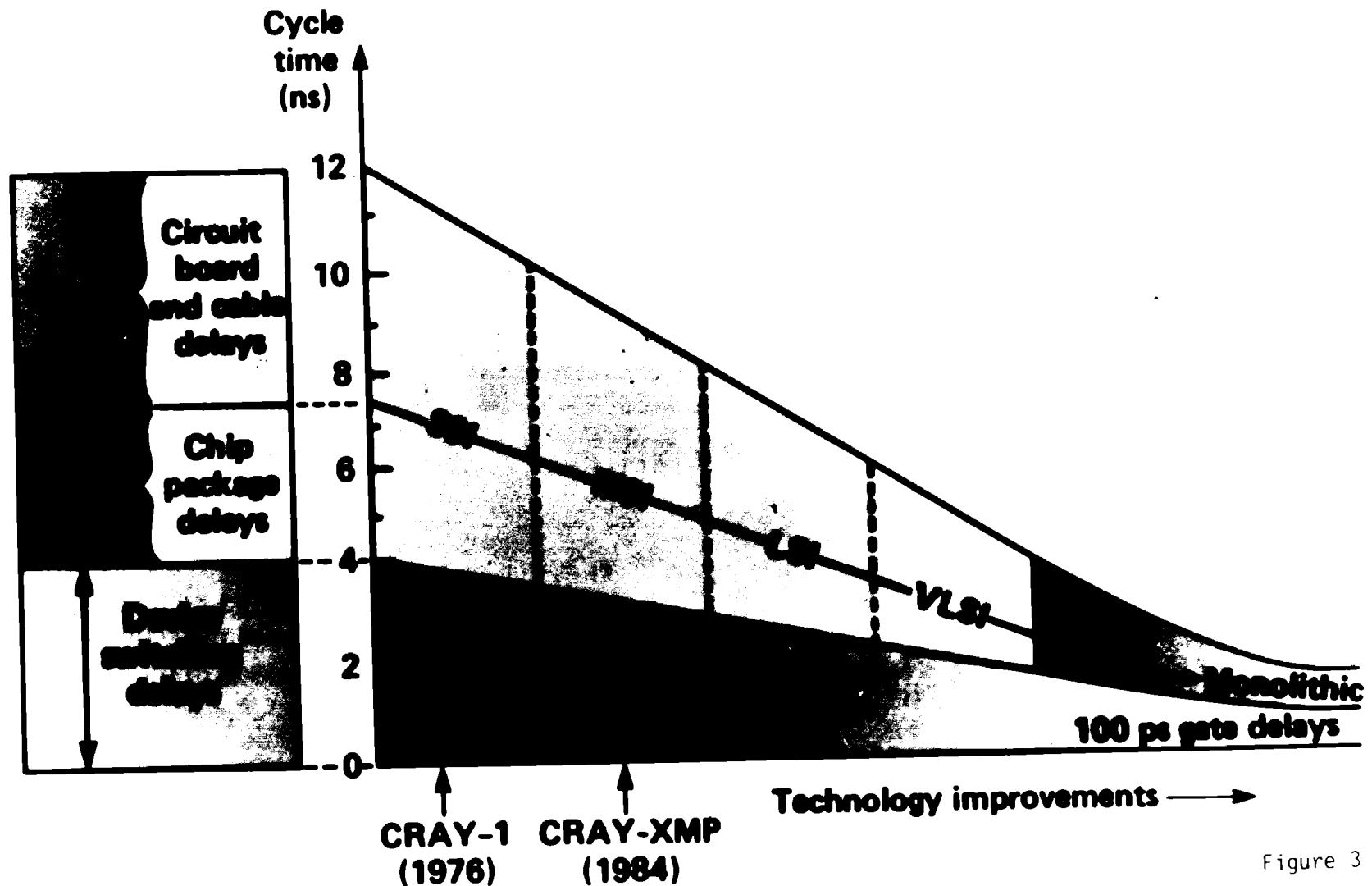
Figure 3

Basic elements of a hybrid WSI circuit

Silicon wafer PC board (actual size, 125-mm diameter)

IC chip mounted on wafer (10 mm square)

10 mm

Wafer section (12X)

1 mm

Chip/chip connections (250X)

50 μm

Chip connections (50X)

250 μm

IC chip section (2000X)

5 μm

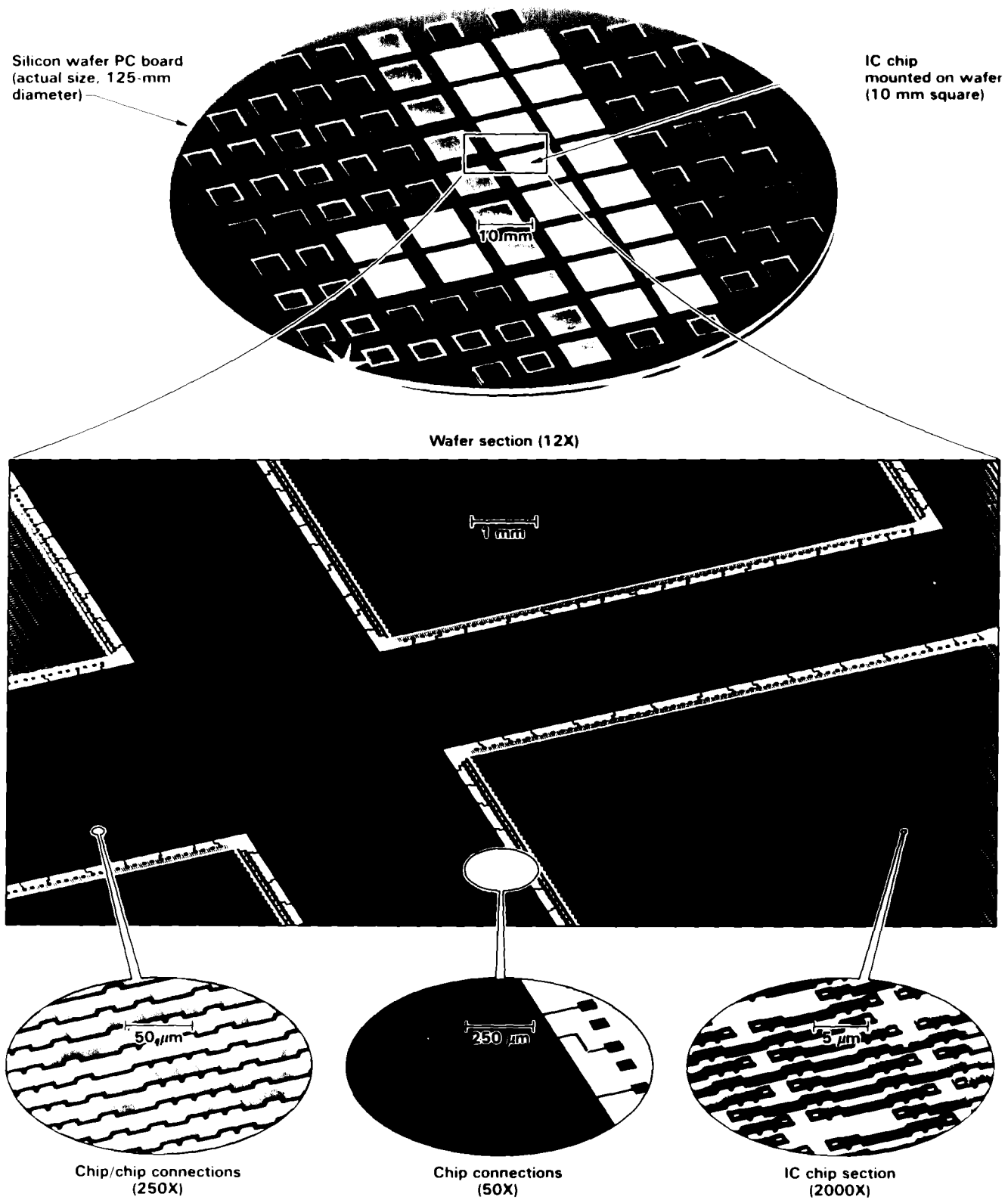Figure 4

Hybrid WSI Packaging Technology

SiO$_2$

Laser-defined
I/O wire

IC chip

Coolant distribution
header

Glass manifold

Gold-dot type
cable-to-wafer
power input connector,
spring-loaded

Coolant fill/
drain and external
heat sink connections
(2) w/quick-disconnects,
as needed

Header and manifold
for heat sink

I/O and power connector
sockets, w/current
pulse-suppression features

Single-use soft
metal gasket
EMP closures (3)

Graded Z surface
coating over Ta
body; minimum 1 cm
thickness everywhere

Ionizing radiation/
EMP structural baffle

Figure 5